Nota Lepi. **44** 2021: 141–151 | DOI 10.3897/nl.44.62801 Research Article

Life history of the rare boreal tiger moth *Arctia menetriesii* (Eversmann, 1846) (Lepidoptera, Erebidae, Arctiinae) in the Russian Far East

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http://zoobank.org/B7F7FE03-41E4-4AC4-9325-34005E06B0F9

Received 5 January 2021; accepted 17 March 2021; published: 14 May 2021
Subject Editor: Théo Léger.

Abstract. A thorough description and detailed photographs of all developmental stages of one of the rarest Palaearctic moths, Menetries' tiger moth *Arctia menetriesii* (Eversmann, 1846) (Lepidoptera, Erebidae, Arctiinae), are presented. Eggs were obtained from a female collected in the Bureinsky Nature Reserve, Khabarovsk Krai, Russia. Data relating to specimens from this region significantly supplements previously published data, which was derived exclusively from more westerly parts of the species' range. Larvae were reared mainly on dandelion (*Taraxacum campylodes* G.E.Haglund) in laboratory conditions. Some larvae were fed on *Aconitum consanguineum* Vorosch. leaves and larch (*Larix gmelinii* (Rupr.) Kuzen.) needles during certain periods of their lives. It is hypothesized that toxic compounds found in these plants resulted in high mortality rates among larvae prior to pupation. Metamorphosis anomalies in the form of larva-pupa intermediates and various morphological defects of pupae are documented for *A. menetriesii* for the first time. The assumptions of some researchers about the important role of *Larix* and *Aconitum* in larval development are questioned.

Introduction

Menetries' tiger moth *Arctia menetriesii* (Eversmann, 1846) is one of the rarest and most poorly studied Palaearctic moth species. Although the adults are large with bright colouration and the species is widespread throughout boreal Eurasia (from Finland in the west to Sakhalin Island in the east), it is primarily known from sporadic, disjunctive occurrences. The species is reliably recorded from Finland, Northern European Russia (Republic of Karelia and Arkhangelsk Oblast), the Urals (Sverdlovsk Oblast), Siberia (Yamalo-Nenets Autonomous Okrug, Khanty-Mansi Autonomous Okrug, Kemerovo Oblast, Altai Republic, Republic of Khakassia, Krasnoyarsk Krai, Irkutsk Oblast, Republic of Buryatia, Zabaykalsky Krai, and Republic of Sakha – Yakutia), Russian Far East (Amur Oblast, Khabarovsk Krai, Primorsky Krai, and Sakhalin Island), Kazakhstan, and North China (?Sungari River) (Hori 1926; Krogerus 1944; Dubatolov 1984, 1985, 1990, 2010; Klitin 2009; Bolotov et al. 2013; Berlov and Bolotov 2015).

The holotype of *A. menetriesii* originated from northeastern Kazakhstan ("Songoria") (Dubatolov 1984). However, no representatives of the species have been found in this territory since its discovery.

For a long time, *A. menetriesii* was included in the monotypic genus *Borearctia* Dubatolov, 1984. Recently, *Borearctia* and 18 other arctiine genera have been synonymized with the genus *Arctia* Schrank, 1802 on the basis of molecular genetic data (Rönkä et al. 2016).

A. menetriesii is included in the Red Lists of both countries it currently inhabits. These are Finland, where it is classified as Data Deficient (DD) (Hyvärinen et al. 2019), and the Russian Federation, where it falls under the category of Vulnerable (Vu) (Order of the Ministry of Natural Resources and Environment of the Russian Federation 2020).

In July 2018, one *A. menetriesii* female was collected by the author in the Bureinsky Nature Reserve in the upper reaches of the Pravaya Bureya River (Khabarovsk Krai, Russia) (Fig. 3A). Previously, two specimens were collected by V.D. Nebaykin in the Levaya Bureya River valley in July 1984 (Dubatolov and Lyubechanskii 2005). The new record was approximately 50 km from previously known localities and is the first record of this species in the region in 34 years. It is worth noting that the author conducted a search in *A. menetriesii* habitat in the upper reaches of the Pravaya Bureya River during its flight period (late June to July) for 13 years (2004, 2009–2020). However, this species was discovered only in 2018, which highlights its extreme rarity. Eggs were collected from a female moth, which made it possible to document the species' biology under laboratory conditions and describe the immature stages.

Little is known about the biology of the immature stages of *A. menetriesii*. Krogerus (1944) provided a description of all stages of *A. menetriesii* development as well as very schematic drawings of the first, fourth, and sixth instar larvae, and the pupa. The immature stages were obtained through rearing eggs from a female collected in Central Finland (Saarijärvi, Pyhä Häkki). Larvae were fed mainly on the leaves of *Taraxacum*, as well as *Plantago* and *Polygonum*, in laboratory conditions. A total of two moths (a female and a male) out of 30 eggs reached the adult stage. Krogerus's (1944) paper also contains information on the discovery of a larva on a spruce trunk in Juupajoki (Southern Finland) in 1920. Subsequently, some features of immature stages were briefly described and illustrated by low-resolution photographs, also under laboratory conditions, by Saarenmaa (2011). However, there is still no detailed description of all immature stages. Eggs were collected from a female sampled in the Northern Transbaikalia Region. A total of 19 adults were obtained from 100 larvae, which fed on 15 plant species, among which the preferred species were *Plantago major* L., *Taraxacum campylodes* G.E.Haglund, *Rubus chamaemorus* L., *Vaccinium uliginosum* L., *Salix phylicifolia* L., *Menyanthes trifoliata* L., and *Persicaria maculosa* Gray (Saarenmaa 2011). In addition, larch (*Larix*) has been suggested as an important host plant for larvae in most *A. menetriesii* habitats (Saarenmaa 2011).

The first reliable data of a natural host plant of *A. menetriesii* was obtained in the Baikal Region, where one last instar larva was found feeding on the extremely poisonous plant *Aconitum rubicundum* Fischer (Ranunculaceae) (Berlov and Bolotov 2015). The larva subsequently died, the presumed cause being starvation since *Aconitum* was not available and other plants were refused (Berlov and Bolotov 2015).

Considering the extreme rarity of *A. menetriesii* and the paucity of data on its biology, this study (1) describes and illustrates all developmental stages of the species; (2) presents the first observations on metamorphosis anomalies of this rare moth; and (3) discusses general patterns of its bionomics in a broader ecological context.

Materials and methods

A female of *A. menetriesii* was collected flying low above the ground in sunny weather after a short shower of rain at 2.30 p.m. on July 1, 2018. Locality: Russia, Khabarovsk Krai, Verkhnebureinsky District, Bureinsky Nature Reserve, Dusse-Alin' Mountains, upper reaches of the Pravaya Bureya River, Novyi Medvezhii cordon, 52°07'56"N, 134°17'30"E, 877 m. The habitat consisted of mountain larch forest composed of *Larix gmelinii* (Rupr.) Kuzen. with open-grown young *Picea ajanensis* Fisch. ex Carr. and *Betula platyphylla* Sukaczev trees. The lower layers were dominated by green moss species, *Vaccinium vitis-idaea* L., *Rubus arcticus* L., and *Ledum palustre* L. Individual bushes of *Salix* sp., *Betula divaricata* Ledeb., *Rosa acicularis* Lindl., *Spiraea beauverdiana* C.K. Schneid., and *S. salicifolia* L. were also present.

The captive female laid 105 eggs on July 3, 2018. First to third instar larvae were kept in ventilated plastic cages in groups of 5–10. Fourth to seventh instar larvae were confined to cages individually or in groups of two per cage. The food was changed twice a day. The cages were cleaned of food waste and frass, and treated with an antiseptic (Miramistin 0.01%) every day to prevent the development of infections. The larvae were maintained in laboratory conditions in the city of Khabarovsk indoors at an average temperature of ca. +25 °C under continuous illumination using three LEDs and daylight compact fluorescent lamps with 21–26 W power consumption. It has previously been established that several boreal arctiine species such as *Arctia ornata* Staudinger, 1896 and *Grammia quenseli* (Paykull, 1793), co-occuring with *A. menetriesii* can complete larval development to adults within two months under continuous illumination, thereby avoiding obligatory winter diapause of larvae that occurs under natural conditions (Koshkin 2020).

Most first and second instar larvae of *A. menetriesii* were fed on *Aconitum consanguineum* Vorosch. leaves, while the rest were reared on dandelion (*Taraxacum campylodes* G.E.Haglund) leaves. All larvae were switched to the dandelion diet at the third instar. Approximately twenty larvae of the sixth and seventh instars were switched from dandelion to larch (*Larix gmelinii*) needles in order to test the hypothesis that *Larix* is an important host plant for *A. menetriesii* (Saarenmaa 2011). Pupae and adults were maintained in entomological cages with cloth walls under natural lighting conditions and temperatures of +23 to 25 °C.

Photographs were taken using a Sony SLT-A65 digital camera with a Sony 2.8/50 macro lens. Voucher material is deposited in the author's private collection.

Results

Description of immature stages

Egg. The eggs are dome-shaped with a flat base and of light green colour (Fig. 1A). The surface sculpture of the chorion is finely meshed; the cells are rounded. The egg height and width are 1.5 and 2 mm, respectively. Eggs develop in approximately 9 days at an average temperature of 23–25 °C.

First instar larva. All thoracic segments, as well as the posterior part of the seventh to tenth abdominal segments, are light orange (Fig. 1B, C). The rest of the body is whitish. The spiracles are pale. The head is black and shiny. Each segment has a row of brown warts with hairs. There are 8 warts on the second and third thoracic segments. The first thoracic segment has two warts on each side and a long wart on top. Each of the abdominal segments, with the exception of the last

Figure 1. *Arctia menetriesii*. **A.** Eggs; **B–O.** Larvae: **B, C.** First instar larva; **D, E.** Second instar larva; **F, G.** Third instar larva; **H, I.** Fourth instar larva; **J, K.** Fifth instar larva; **L, M.** Sixth instar larva; **N, O.** Seventh instar larva; **B, D, F, H, J, L, N.** Lateral view; **C, E, G, I, K, M, O.** Dorsal view.

three, contains 12 warts. Of these, the four largest are located on the dorsal and in the upper parts of the lateral body surfaces. Two small warts are situated at the axial body region and displaced forward relative to the large warts. Round brown spots are found between these warts on the first and seventh abdominal segments. The eighth abdominal segment has only 10 warts; the lowest ones are absent. There are four warts on the ninth abdominal segment; the two largest warts are on top. A large wart is situated on the anal shield on the last segment. Each dorsal and upper lateral wart bears one short black hair. Large warts on the dorsal side of the eighth to tenth abdominal segments have additional white hairs. The rest of the warts bear only white hairs of varying lengths. Thoracic legs and prolegs are brown. Body length is 3–5 mm. Instar duration is 2–3 days when fed on *Taraxacum* and approximately 5 days when fed on *Aconitum*.

Second instar larva. The general colouration of the head and body is similar to that of the first instar (Fig. 1D, E). The warts are larger and vary in colour. The two rows of large warts on the dorsal side of the first to seventh abdominal segments are black, shiny, and sharply distinguished against the general background. Two additional wart rows on the dorsal side of the first and seventh abdominal segments are also coloured black. There are black spots between them, thereby creating the appearance of two large black spots on the top of these segments. The remaining warts on the first to seventh abdominal segments are light brown. Warts on the thoracic and the last three abdominal segments are light orange and identical to the main ground colour. Each wart has an average of five whitish and five black long hairs. The thoracic legs and prolegs are light orange. Instar duration is 3 days when reared on dandelion.

Third instar larva. Similar to the second instar in general (Fig. 1F, G). The exceptions are a brighter orange colouration of the thoracic and the eighth to tenth abdominal segments, and paler lateral and two dorsal rows of small warts on the first to seventh abdominal segments, which hardly stand out against the general whitish background. Large warts on the dorsal side of the second to sixth abdominal segments are bicoloured: black with a bluish tinge on the outside and whitish on the inside. Warts on the dorsal side of the first and seventh abdominal segments form black spots identical to those in the second instar although larger in size. Small dark spots forming two dark dashed lines along the dorsal side are located between the large warts of the abdominal segments. Each wart has up to 11 black and yellowish hairs of different lengths. The black hairs are found exclusively on the dorsal body surface. Instar duration is three days when fed on dandelion.

Fourth instar larva. Very similar to the third instar, differing from it in more pronounced dark lines on the dorsum (Fig. 1H, I). Instar duration is about 5 days when reared on dandelion.

Fifth instar larva. Resembles third and fourth instars larvae, while differing from them in pale warts on the dorsal side of the second to sixth abdominal segments and two well-marked longitudinal dark lines (Fig. 1J, K). Warts on the first and seventh abdominal segments form large dark spots. Small dark spots are situated on the dorsal side of the eighth and ninth abdominal segments. Spiracles are oval, light yellow with a light brown margin. Instar duration is approximately 6 days when fed on dandelion.

Sixth instar larva. The colouration differs significantly from the larvae of the earlier instars (Fig. 1L, M). The head is black. The lateral body sides are either beige or light yellow. The dorsal side is black with a long, wide orange-yellow stripe in the center. Pale colouration on the thoracic segments is brighter, of orange colour. The ventral surface is gray. Warts are large, white, with the exception for those located on the thoracic and last abdominal segments, which are white and orange. There are dense tufts of long hairs on the warts: they are black and light brown on the dor-

Figure 2. *Arctia menetriesii*. **A–C.** Pupa with insignificant anomalies; **D–F.** Pupa with severe anomalies; **G.** Pupa in silken cocoon; **H, I.** Cremaster; **J–L.** Female emerged from larva-pupa intermediate (**J, K.** Head and thorax left covered with the larval cuticle; **L.** Larval cuticle removed); **M, N.** Lethal larva-pupa intermediates; **A, D, H.** Ventral view; **B, E, G, K, N.** Lateral view; **C, F, I, J, L, M.** Dorsal view.

sal side and light brown on the lateral sides. The spiracles are white, with the exception of those located on the second to third thoracic segments, which are black. The thoracic legs and prolegs are light orange. Body length up to 35 mm. Instar duration is approximately 12–14 days when fed on dandelion and approximately 20 days when reared on larch.

Seventh instar larva. The larva differs significantly in appearance from the earlier instars and has an overall stockier build (Fig. 1N, O). The head and body are black. A central orange stripe runs along all the segments on the dorsal side. The spiracles are oval, light yellow, and clearly visible against the general background. The head capsule is 3.8–4.0 mm in height and 4.0–4.2 mm in width. All warts are white, large, and have dense tufts of black hairs. Small blotches of paler hairs

are situated between these tufts. Each wart bears up to 40 or more hairs. The thoracic legs are dark brown; prolegs are paler. Total length up to 45 mm shortly before pupation. Instar duration is 21–30 days when fed on dandelion.

Pupa. Total length is 21.5–24.0 mm (average length 22.9 mm); maximum width is 7.5–9.0 mm. Pupa is almost entirely black or brown, slightly shiny (Fig. 2A–F). The cuticle is smooth with a thin coating of bluish-grey wax. Antennae, legs, and proboscis are well developed. Labial palps are visible as small triangular areas at base of proboscis. Antenna is long, extending to 5/6 of the forewing length. Proboscis is long, reaching the level of the antennal apex. Prothoracic legs are slightly shorter than proboscis; mesothoracic legs reach the level of the antennal apex. Metathoracic legs are visible only in distal parts, reaching the level of the wing apex. Abdominal spiracles are narrow, slightly rising above the cuticular surface. Abdominal segments with distinct short setae are arranged around scars of larval warts. The cremaster has a medial groove and two groups of 8–10 brown nail-like setae (Fig. 2H–I). The pupa is in a loosely spun whitish silken cocoon covered with larval hairs (Fig. 2G). The development of the pupae takes 9–10 days.

Adult. The forewing length is 31 mm for a wild female, 25–29 mm for reared males, and 28–31 mm for reared females. The ground colour of the wings is either yellow or yellow-orange. The forewing and hind wing of a wild female are bright orange-yellow and identical in colour (Fig. 3A). The forewings of reared specimens are paler than the hind wings (Fig. 3B–F). The pattern is formed by black stripes running along the veins and black transverse medial and subterminal lines, which can be partially reduced. The black discal spot is clearly visible both on the forewings and hind wings. The costal margin of the hind wing is red. Some reared specimens also have a reddish outer margin to the hind wing. The pattern of the wing underside is identical to that of the upperside, although slightly paler; the costal margin of the forewing is red. The antenna is black, serrate in males and filiform in females. The top of the head is red, and the forehead is black. The labial palp is black dorsally and red ventrally. The patagium is black, with a yellow anterior and a red posterior margin. The tegula is black, yellow on the outer margin. The upper side of the thorax is black with two longitudinal yellow stripes. The abdominal segments are black dorsally and ventrally, and orange along the margins. The front and middle legs are black dorsally and yellow ventrally; the coxae and femora have red hairs. The hind legs are yellow.

Developmental features. Low to moderate mortality was observed among larvae of the first to sixth instars. However, approximately 75% of larvae that reached the last instar died immediately before pupation.

A significant number of metamorphosis anomalies occurred during pupation. Some of them manifested as larva-pupa intermediates due to disrupted moulting (Fig. 2J–L, M, N). Four specimens exhibited this anomaly, only one of which completed metamorphosis to adult (female); the remaining three died. Upon adult emergence, the surviving larva-pupa intermediate broke free of the pupal cuticle at the abdominal segments, while the head and thorax were left covered with the larval cuticle (Fig. 2J, K). This female laid 19 unfertilized eggs. Eventually, the larval cuticle was mechanically removed, leaving the fully formed head and thorax of the imago (Fig. 2L). The antennae, legs, and wings remained in a reduced state. The rest of the anomalies were pupal (Fig. 2A–F). They manifested themselves as abnormal positions of the legs, antennae, and wings, as well as uneven pupal colouration.

Fourteen larvae reached the pupal stage. One of the most malformed pupae died. Although the remaining 13 survived to adult eclosion, only four adults (two females and two males) fully or al-

Figure 3. *Arctia menetriesii*. Adults: **A.** Wild female (Khabarovsk Krai, Bureinsky Nature Reserve, Novyi Medvezhii cordon); **B–F.** Reared specimens: **B, E.** Female; **C, D, F.** Males; **E, F.** Live specimens.

most fully spread their wings (Fig. 3B, D–F); one male had a severely deformed left forewing (Fig. 3C). The rest of the adults were unable to inflate their wings. All pupae had anomalies of varying severity. Pupae with insignificant anomalies transformed into adults with fully or almost completely formed appendages. Pupae with severe anomalies produced adults that were unable to inflate their wings. Similar metamorphosis anomalies were described for *Spodoptera littoralis* (Boisduval, 1833) and *S. exigua* (Hübner, 1808) (Lepidoptera, Noctuidae) reared on food supplemented with azadirachtin and methoxyfenozide (Martinez and van Emden 2001; Enriquez et al. 2010).

The adults hatched on September 12–23, 2018. The development cycle of *A. menetriesii* from oviposition to adult emergence took 72–83 days under laboratory conditions.

Discussion

The description of the immature stages of *A. menetriesii* provided here supports in general and significantly expands on the information available for this species from Europe and Transbaikalia (Krogerus 1944; Saarenmaa 2011). Some differences are found in the appearance of the second to

fifth instar larvae and pupa. According to data from Finland, the paired spots on the first and seventh abdominal segments are reddish brown in the second and third instar larvae (Krogerus 1944). According to our data, they are black. There is also an indication that the longitudinal dark lines on the first to seventh abdominal segments appear only at the fifth instar. According to our data, the lines are clearly visible in the fourth instar larvae, and even more pronounced at the fifth instar. In addition, according to data obtained in Finland, the cremaster contains 10 setae, while we counted 14 to 20 setae in our study.

The unusually low ratio of resulting adults compared to the initial number of eggs is similar to the results obtained by other researchers (Krogerus 1944; Saarenmaa 2011). This is due to a high mortality rate among last instar larvae and numerous metamorphosis anomalies. The latter may be caused by larval ingestion of secondary plant compounds, such as those found in *Aconitum* leaves and possibly also larch needles. The norditerpenoid alkaloids in *Aconitum* are known to have strong insecticidal activity (Gonzalez-Coloma et al. 2004). It is necessary to further establish the role of *Aconitum* in *A. menetriesii* larva diet and the effect of norditerpenoid alkaloids on larval development and mortality. It is possible that *A. menetriesii* larvae partly feed on *Aconitum* to gain alkaloids as a defense against predators in natural conditions, but that too much *Aconitum* can be lethal. This is exactly what other tiger moths do, and has been well-studied in *Grammia incorrupta* (H. Edwards, 1881), for example (Mason et al. 2014; Christian Schmidt, pers. comm.). Perhaps this explains the discovery of *A. menetriesii* larva on *Aconitum* (Berlov and Bolotov 2015). Despite an active search for aconite through the habitat in which the *A. menetriesii* female was collected in the upper reaches of the Pravaya Bureya, it has never been seen there. Small groups of aconite plants (*Aconitum* cf. *macrorhynchum*) are located 5 km away across a mountain pass in the valley of the Niman River. Considering the low activity of the adults and the good condition of the collected moth, it is unlikely that the latter had flown from there. No larvae of any moth species or damage done by them were found during a detailed examination of aconite plants from the Niman River valley in various years. In addition, the effect of a number of substances contained in larch needles on *A. menetriesii* larva development has to be established. Despite the assertions of colleagues on the important role of larch in larval diet (Saarenmaa 2011), all the larvae fed on this plant died before pupation in our case. Meanwhile, several larvae in the middle of the last instar, which were switched back to rearing on dandelion leaves, succeeded in pupating.

It is worth noting that no metamorphosis anomalies of the immature stages were observed when rearing two other arctiine species (*Arctia ornata* and *Grammia quenselii*) coexisting with *A. menetriesii* on a dandelion diet under the same laboratory conditions.

Menetries' tiger moth is extremely rare since the adults are difficult to detect, as they are not attracted to light, are either diurnal or crepuscular, and fly reluctantly. It is possible that larvae are also subject to high mortality in nature due to the metamorphosis anomalies observed in this study. Additionally, high mortality due to parasitoids may also be the case, as has been found in other arctiine species from the same region. For instance, *Arctia ornata* occurs sympatrically with *A. menetriesii* in the study area. All 23 sixth-instar larvae of this species collected there in July 2017 were parasitized by the larvae of a tachinid fly (Diptera, Tachinidae). It has been shown that parasitoid infestation significantly reduces imago abundance in several other arctiine species from Siberia (Shilenkov and Richter 1998) and the Arctic (Bolotov et al. 2015).

Further studies on the ecology of *A. menetriesii* are required in order to determine what biotic and abiotic factors determine the low abundance of the species in nature and to develop a management plan for its conservation.

Acknowledgements

I am sincerely grateful to Dr. Christian Schmidt (Ottawa, Canada) for carefully reviewing the manuscript and providing valuable comments and ideas. The author is also grateful to Dr. Ivan N. Bolotov (Arkhangelsk, Russia) and Dr. Nikolay A. Ryabinin (Khabarovsk, Russia) for careful reading and valuable comments on the manuscript. Special thanks go to Dr. Anatoly A. Nechaev (Khabarovsk, Russia) and Evgeny V. Novomodny (Khabarovsk, Russia) for their help in identification of *Aconitum consanguineum*.

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